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Discussions

Interactive comment on "The European mountain cryosphere: A review of past, current and future issues" *by* Martin Beniston et al.

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General

The submitted paper prepared by 25 authors seems to have resulted from a workshop held at Riederalp, Switzerland, in March 2016. It is voluminous, containing roughly 13'000 words of text and about 400 to 500 references (many citations in the text are still missing in the reference list). Its title and goals are ambitious: to provide a review on the "state of knowledge in terms of the observed evolution of European mountain cryosphere and associated impacts" with respect to "past, current and future issues". This sounds fascinating and important as snow and ice in Europe are undergoing rapid changes with long-term and far-reaching consequences beyond science. The many publications discussed in parts of the text (latest work could still be added in places)

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indeed reflect the intense ongoing research activity in the field. Expectations are thus high concerning take-home messages to be found or focused recommendations for future research and application.

About one half of the 25 authors covers various aspects related to the domain of snow, solid-liquid precipitation and avalanches in mountains. The corresponding discussion distributed over various sections of the paper is extensive and quite comprehensive (no illustration). Four authors (three from the Alps, one from Norway) provide a shorter and somewhat narrower treatment on glaciers, primarily emphasizing glacier mass balance and water in the Alps (one illustration). Only one author (?) seems to treat permafrost (three illustrations, many citations are missing in the reference list). The contributions about the wide field of ecosystems in connection with snow, permafrost or glacier fore-fields appear to remain marginal if not random (two case studies from zoobiology, two illustrations). Geomorphology (two to three authors?) mainly relates to hazardous phenomena but largely ignores landscape change with options for use but also new risks. General thoughts about uncertainty/communication (2 illustrations) are correct but not specific to Europe, mountains or the cryosphere. Snow and ice research in the Scandinavian mountains seems to be rather weakly represented and options offered by the explosive development of remote sensing capacities and new surveying technologies could be a stronger focus. The conclusions of the paper elaborate on general aspects concerning data availability and communication but – surprisingly enough – say nothing concrete about the state of knowledge, the evolution or practical impacts related to the mountain cryosphere in Europe, nor do they provide specific recommendations for focused research. This leads to the impression that the contribution in its present state constitutes a rather preliminary “workshop report”. Transforming it into a systematic, balanced, critically reflected and focused scientific review about the European mountain cryosphere with essential messages and concrete recommendations would need additional steps requiring deeper reflection about topics/sources, more synthesis/weighting efforts, a clearer/more systematic structure and especially consensus-finding about key messages and recommendations for the future. The following thoughts (mainly on glaciers, permafrost, geomorphology/hazards and landscape change) may indicate some possibilities.

Reviews on mountains or on snow and ice in the context of climate change have been published before. Most recently, not only the latest IPCC assessment reports but also three new books provide comprehensive overviews and contain rich information: CUP's "The High Mountain Cryosphere" (2015), Elsevier's "Snow and Ice-Related Hazards, Risks, and Disasters" (2015) and Wiley's "Remote Sensing of the Cryosphere" (2015). Already the introduction of the submitted paper should mention the availability of such important sources and clarify what exactly the goals and added values could be of a special focus on Europe. What are the "issues" mentioned in the title: observations, process understanding, modeling, scenario development, impact assessment or communication with the public/policymakers, etc.? To what do the terms "past", "current" and "future" relate: To the historical development of observational strategies, to major steps in scientific progress, to emerging research fields, to changes in nature, to time scales of years, decades, centuries, etc.? What was the concept for the reflection and synthesis procedure beyond compiling and enumerating many publications (especially of seven key authors with their names in up to 25 references each)? Was the intention to break the results down into key messages or should this be left open on purpose? What are the logics behind the structure of the presentation?

The structure of the presentation could be more systematic and transparent. The introduction should formulate the main questions and the conclusions should provide corresponding answers. The subsections of chapter 2 on the cryosphere components should all follow the same scheme for better comparison; section 2.1 is a good example with a brief general introduction followed by a summary of observed changes and then a discussion of likely future changes. All impacts could be treated in a chapter 3, while chapter 4 could focus on special challenges; here an explanation would have to be given about the reasoning behind the corresponding selection of topics.

Throughout the text but especially concerning model approaches, needs and priorities for process understanding should be clearly discriminated from needs and priorities concerning impact assessments and practical applications. As an example, some short remarks on page 20, lines 25-29, refer to the results of an inter-comparison project concerning models for ice thickness estimates. Here, it could be mentioned that sophisticated flux-related approaches reflect our complex scientific understanding and are needed for sensitivity analyses but must be heavily tuned, etc. In practical applications, transparency, robustness, easy application or limited data requirements in simple stress-driven models (which need no excessive tuning and perform equally well) can be a serious advantage. In fact, realistic modeling of glacier bed topographies and DEMs without glaciers over large mountain areas (Linsbauer et al. 2009, for example) as probable future topographies has been a fundamentally important innovation. This step had been made possible by the combination of 3D approaches (already introduced by WGMS in the 1990s using the example of the European Alps) with digital terrain information. It opened the door for the emerging research field dealing with future landscapes in de-glaciating mountain chains and could well be one of the key messages of the review. This example illustrates that a systematic differentiation – who needs what? – may help with breaking down the extensive discussions into key messages of interest even for non-scientific circles.

Another question relates to the significance and relative importance of the presented information. As an example, mentioning early point observations on glaciers in the Swiss Alps (page 5, line 31) provides a historical dimension to the section on glacier observation. But what do we learn from this in comparison with, for instance, the repeated precision mapping of glaciers in the Eastern Alps since the end of the 19th century (not mentioned)? Already in 1894, glacier observations became internationally coordinated with the participation of the European countries being the backbone of this remarkable step. Later, several integrative treatments of all glaciers in the European Alps have been published, marking major steps in the development of worldwide glacier monitoring. The inventory analysis in 1995, for instance, was a pioneer effort elaborated on behalf of UNEP for estimating various physical parameters (including shear stresses, response times or thermal conditions, etc.) for all glaciers and provided the first reliable estimates of ice thicknesses and volumes. The comprehensive treatment in 2007 used the example of the European Alps for illustrating the integrated tiered monitoring concept developed for the Global Terrestrial Network for Glaciers (GTN-G) within the terrestrial component of the Global Climate Observing System (GCOS in support of UNFCCC, not mentioned), i.e. at highest scientific and political levels. Integration of length and mass change data with the "dynamic fitting" concept (Oerlemans 1998; Climate Dynamics) within the framework of the international ICEMINT project among other integrative analyses (for instance, Zemp et al. 2006; Geophysical Research Letters) already showed many years ago with simple but physically sound models and techniques that the glaciers of the European Alps would largely disappear within decades even with moderate climate scenarios (see also Salzmann et al. 2012 concerning effects of a global 2° goal; Environmental Research Letters). This is important to mention – especially concerning impacts/adaptation – because it documents that results from simple as well as complex model simulations concerning future glacier evolution in the European Alps have been available and robust for many years now (not everything is uncertain). In a similar way, information on long-term commitments concerning continued glacier shrinking due to delayed responses (Mernild et al. 2013, TC 7/5) should also be included, because it shows that it is most probably too late now to save more than small remains of the European glaciers. Such critical reflection about the relative importance and innovative input of the available scientific literature could again help with focusing on essential messages.

A review or even "comprehensive assessment" about such complex matters as "the mountain cryosphere in Europe" cannot deal with everything but should at least mention what is being left out. In the submitted paper, lake ice with some long observational series and in cases heavy touristic use (St. Moritz, for instance) belongs to this category. Ice core drilling in cold high-altitude firn areas (for instance, Monte Rosa or Mont Blanc) should be mentioned as providing important information about pollution in industrial times and even climatic conditions during the Holocene. Mention should be made of cold miniature ice caps at lower altitudes (Oetztal iceman, Juvfonna in Norway, recent Ortles drilling) about cold/millennia-old ice now or soon melting away, indicating that the reduction in ice extent in European mountains may presently be exceeding variability ranges during pre-industrial times. Warming up and degradation of rock glacier permafrost which has persisted during the last about 10,000 years as documented in permafrost core drilling (for instance, Lazaun, South-Tirol) would also be an essential process characterizing the state of the mountain cryosphere. And how realistic are attempts to save glacier ice with white blankets or even artificial snow?

Discussions in the paper in most cases apply a rather linear/sectorial approach. Essential challenges relating to the rapid changes in the cryosphere, however, concern interactions and integrated systems including humans and their infrastructure, especially in densely inhabited regions like the Alps. Fall, winter and spring snow plays a key role concerning subsurface thermal conditions and perennially frozen ground on more gentle slopes but less so in steep rock faces. The stability of steep/cold hanging glaciers on rock walls strongly depends on basal ice temperatures and related permafrost conditions in bedrock, an issue often ignored in the corresponding literature. Vanishing ice at the surfaces of rock walls can enlarge effects from rising air temperatures with respect to freeze/thaw cycles, frost weathering, permafrost degradation and rock fall activity. One of the most important topics, which should be included in a paper about the mountain cryosphere, is the rapid development of new landscapes – an important emerging field of research and climate change adaptation. Dealing with this topic necessitates a systems approach including socio-economic aspects. An example are the numerous new/future lakes which create opportunities for hydropower, tourism or water supply but also increase risks from impact/flood waves created by large rock/ice avalanches. The terms “hazard” and “risk” should thereby be clearly discriminated. Concerning hazards, a clear discrimination should also be made between processes/phenomena (avalanches, floods), which are mainly driven by short-term weather conditions and have a stochastic-type of temporal occurrence patterns on one side, and cumulative processes/phenomena (glacier vanishing, permafrost degradation, slope stability, land-

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scape change), which now continuously evolve over longer time intervals. For the latter, the future will not only be different from the past but also from the present. This requires a specific and rather difficult hazard-prevention and risk-reduction strategy (scenario-based assessments including socio-economic aspects) to be developed and applied. A deeper understanding of future conditions in nature also requires consideration of different response characteristics related to the involved cryosphere components and the corresponding geo- and ecosystem factors. While glacier vanishing now is a matter of decades, permafrost degradation or slope destabilization can take centuries if not millennia to come. This means that European high mountain regions are experiencing a rapid transformation from glacial to periglacial landscapes with extreme disequilibrium conditions concerning slope stability, sediment cascades, or vegetation cover, etc.

Back to the conclusions, which may be the critical aspect concerning the value of the product: A number of bullet points formulating key messages and recommendations would help. They would document the necessary analytic reflection and synthesis process, thereby making the difference between a heterogeneous workshop report and a systematic, balanced, critically reflected and focused scientific review with a clear added value as compared to already existing modern reviews on mountains and the cryosphere.

Specific remarks

Specific remarks and suggestions can be found in the annotated file. The reference list is variable in style and largely incomplete (citations in the text not contained in the reference list are marked in pink). Careful editing is necessary.

Please also note the supplement to this comment:
http://www.the-cryosphere-discuss.net/tc-2016-290/tc-2016-290-RC1-supplement.pdf

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